CORRIDOR measurement campaign

This document describes some background information on the tools used for the post-processing of the CORRIDOR measurement data. All the code that is referenced in this document can be found in the OpenAirInterface SVN repository in openair4G/trunk/targets/PROJECTS/CORRIDOR.

# Design of the sounding signal

The sounding signal will occupy 3 channels

* 5MHz at 771.5 MHz (channel 1)
* 10MHz at 2.605GHz (channel 2a)
* 20MHz at 2.590GHz (channel 2b)

The sounding signal is an OFDM signal with specifications taken from the LTE standard. The following table summarizes the main parameters.

|  |  |
| --- | --- |
| Frame length | 10 ms |
| Symbol duration | 66 μs |
| Prefix length | 16 μs |
| OFDM size | 512/1024/2048 |
| Useful carriers | 300/600/1200 |

The first symbol of each frame contains the LTE primary synchronization sequence (PSS) and the rest of the signal is filled with OFDM modulated random QPSK symbols. In order to minimize inter carrier interference (ICI) in high mobility scenarios, we only use ever second subcarrier. In case multiple transmit antennas are used, we use the following pattern:

Figure 1: Pilot patterns for 2 (left) and 4 (right) TX antennas

The sounding signal can be generated with the script generation\_ca.m, which generates the file ofdm\_pilots\_sync\_30MHz.mat. A pre-computed version of this file is also on the SVN server, which is the one used for the measurement campaign (since the generation of the signals uses a random number generator, the signals might be different on different machines).

## Notes on signal design

*If we assume a maximum speed of v=300km/h and the two carrier frequencies f1=800MHz and f2=2.6GHz, then we get Doppler shifts of fd1=222Hz and fd2=723Hz. Using the OFDM symbol time of LTE Ts=66.7 μs (subcarrier spacing of 15kHz), we can compute the ICI as [1, eqn (5.15)]  
  
P\_ICI = 1-sinc^2(fd Ts)   
  
and get P1=-31dB and P2=-21dB. In my opinion this is already quite low and for most of the cases (unless we are very close to the base station) even below the measurement SNR. To be on the safe side we could use every 2nd spacing (subcarrier spacing 30kHz) for the higher frequency, which would give P2=-27dB, but I would not go much lower than that.*

# Data collection

We save the raw IQ data of all antennas in real-time. The data of the 5MHz channel at 771.5 MHz and the 30MHz channel at 2.6 GHz are stored independently. In order to get good resolution for the Doppler profile estimation (see below), we should at least store a continuous chunk of 1 sec. Due to the enormous amount of data and limited write speed of the data (even with a RAID 0 system), for the 30MHz channel at 2.6GHz we only save 1 second out of 2. For the 5MHz channel at 771.5MHz, we can save all the data continuously.

# Post processing

There are two scripts for post processing, one for channel 1 (emos\_read.m) and one for channel 2 (emos\_read\_ca.m). The filename and the number of antennas has the be adjusted. The different algorithms used in the script are explained in more detail below.

## Synchronization

Synchronization it is the most important part of the Post processing. In OFDM systems, there exist three different problems related to synchronization: The first one is the time offset (or symbol synchronization), the solve of this problem allows the receiver to determine the start point in the received OFDM symbol. The second one is the frequency offset (or frequency synchronization), which tries to eliminate the carrier frequency offset caused by the mismatch from the radio frequency local oscillators and the Doppler shift. Finally, the last issue is the sampling clock synchronization, which manages to synchronize the sampling frequency between transmitter and receiver, because both of them work with different physical clocks.

If we ignore the channel dispersion, isolating these offset problems (with out the sampling clock synchronization). The model for the received signal becomes [van de Beek reference]

where is the unknown valued delay and is the unknown carrier frequency offset, is the AWGN and is the number of samples.

The above problems we will be solved with use of known symbols (synchronization sequence) by the transmitter. At the literature there are a lot of works which they don’t use synchronization sequence for achieve higher throughput but they use the knowledge, that there is cycle prefix in the symbol. This way is less accurate and more complex.

### Time offset

To define the start of the frame we make cross correlation between our received data and the (known) synchronization sequence (pilots) which is in the beginning of every frame.

We suppose that we have line of sight, or generally, we don’t have any weird geometry (at not- line of sight case) which is not give us maximum of the cross correlation at the beginning of every frame.

Where is the received samples and is the synchronization sequence, “” is the convolution operator and is our estimate for the initial sample.

An example result of the cross correlation is seams in Figure 2 (All of the plots below are for real measurements which the is stable In the ground and the at a high speed train ).

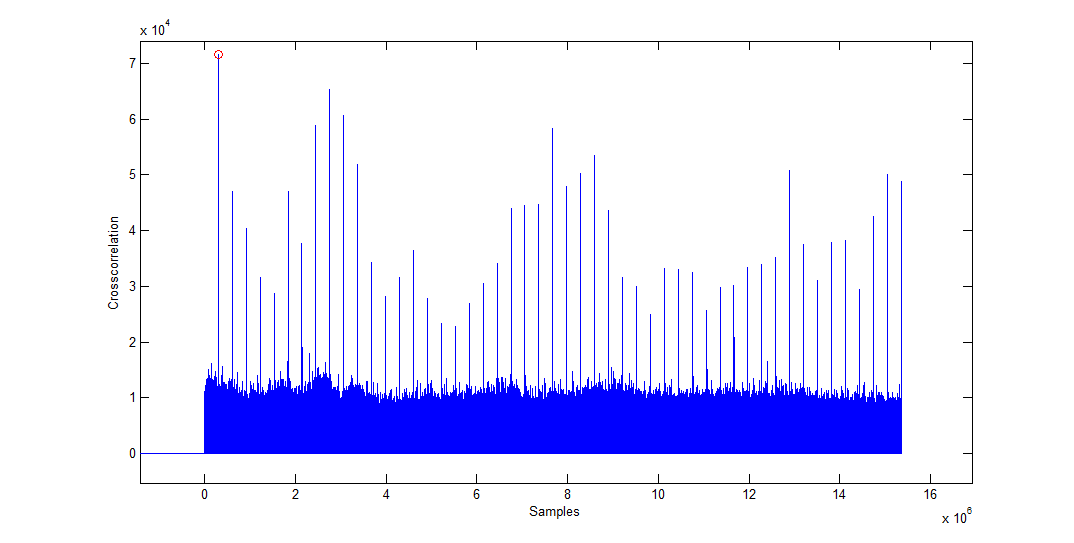


Figure 2: Cross Correlation

The procedure is the following. We reshape the correlation samples to matrix where is the # of frames and is the samples per frame (we have chosen the form the beginning). We compute the maximum of each row of the matrix. We hold only the rows which have maximum over a threshold (we put the threshold heuristically), we sort with respect of ceil index the maximums of the rows and we chose as time offset the median value of these procedure.

At Figure 3 we present one example of the above procedure. The colored samples are with the maximum Crosscorrelation of each row, with the red are the maximums which are over the threshold and with orange are the maximums which are under the threshold. Thus in this example if we sort the index’s we take so the median (and the estimated time offset) it is 130.



Figure 3: Time offset estimation

### Frequency offset

At this subsection the goal is to eliminate the frequency offset which offset caused by the mismatch from the radio frequency local oscillators and the Doppler shift. The most important effect of a frequency offset between transmitter and receiver is a loss of orthogonality between the subcarriers resulting in ICI. The characteristics of this ICI are similar to white Gaussian noise and lead to a degradation of the SNR. For both AWGN and fading channels, this degradation increases with the square of the number of subcarriers.

Taking as granted the beginning of the frame , from the time offset solution we calculate the frequency offset by the angle between the OFDM symbols. From [4] we take

is the number of consecutive symbols. So the offset is estimated by

### Sampling clock synchronization

The different physical clocks of the transmitter and receiver they cause a drift in time. The reason is simple, if the duration of one sample in the oscillator of transmitter is and the duration at the oscillator of the receiver is . Even if we have perfect estimation for the beginning time, If the after samples the receiver it has drift one, Figure 4.



Figure 4: time drift

There are different ways to avoid that problem. The first solution is to can make least squares fit at the beginning of every frame to find the for each sample. After that we can make Lanczos resampling [5] at the correct time. At Figure 4 we see that we fix the problem of time drift, but this procedure takes so much time that at the end is inapplicable.

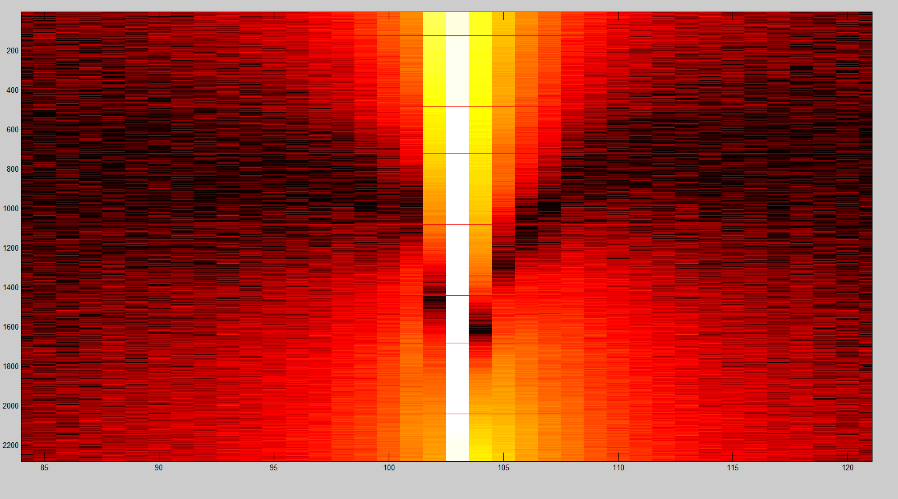


Figure 5: Lanczos resampling

The second approach it is this that we totally follow. After the channel estimation we calculate when the channel has the maximum power in respect to the time delay. If this maximum is over some boundaries we shift it at the “zero” delay.

## Power delay profile estimation

At the next figures we can see the power delay profile estimation for some measurements from the trains. We have a MIMO, and we use two different carriers. We look at three separated scenarios, at the first, one antenna it transmits with line of sight with train and the other is looking at the opposite direction so we expected to measure only noise, Figure 6. At the next play we have exactly the opposite, Figure 7. At both scenarios we see only one carrier for saving space reasons. At the last scenario Figure 8, Figure 9, we see the power delay profile in the case which both of antennas are “looking” the train so we are receiving signal at all links.

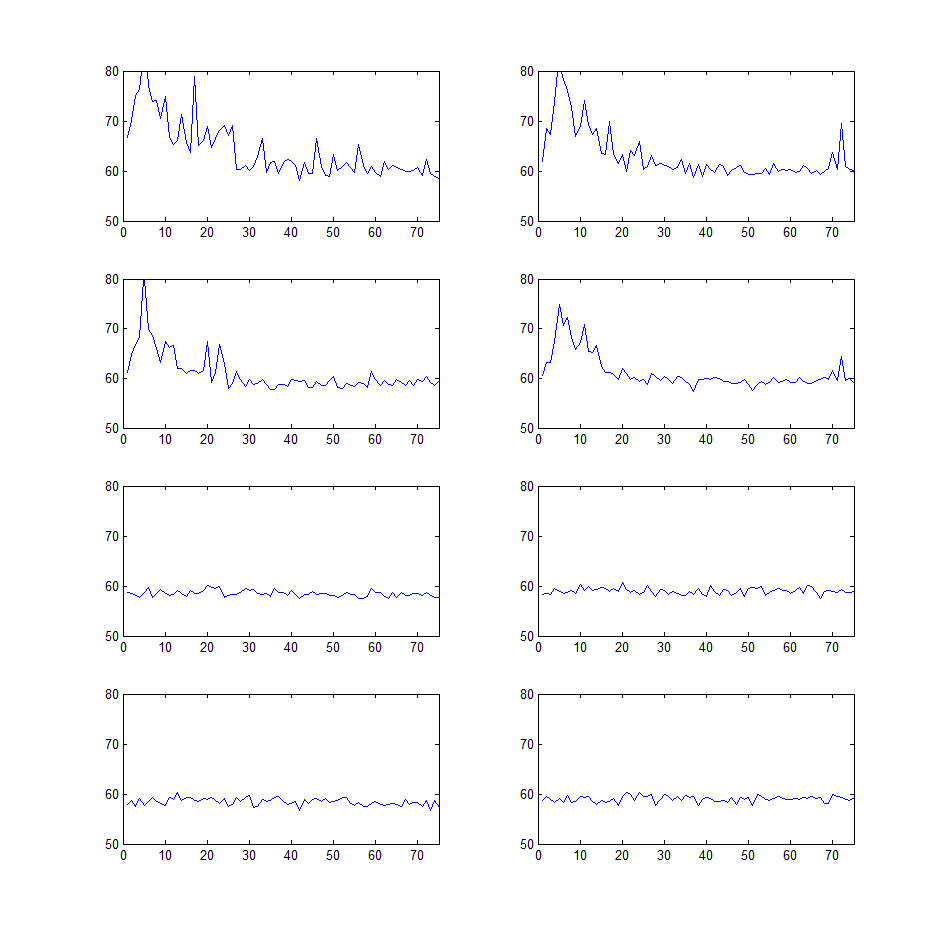
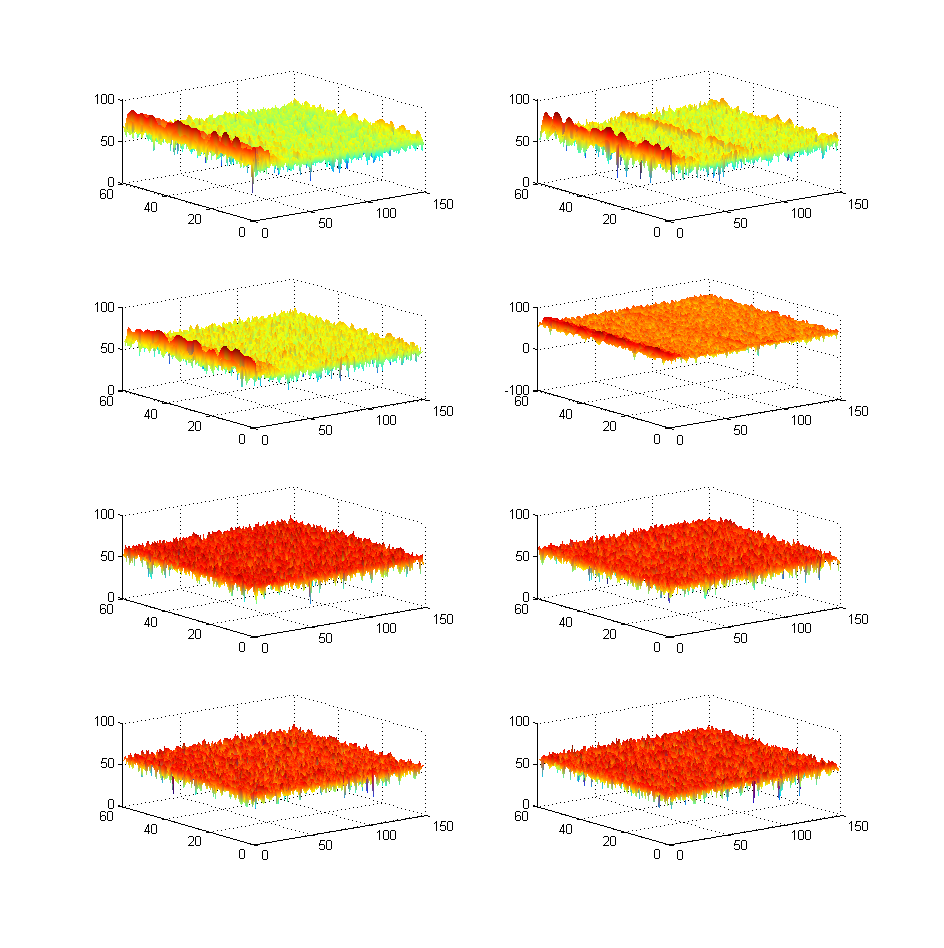


Figure 6: The first antenna has LoS and the second transmits at the opposite direction

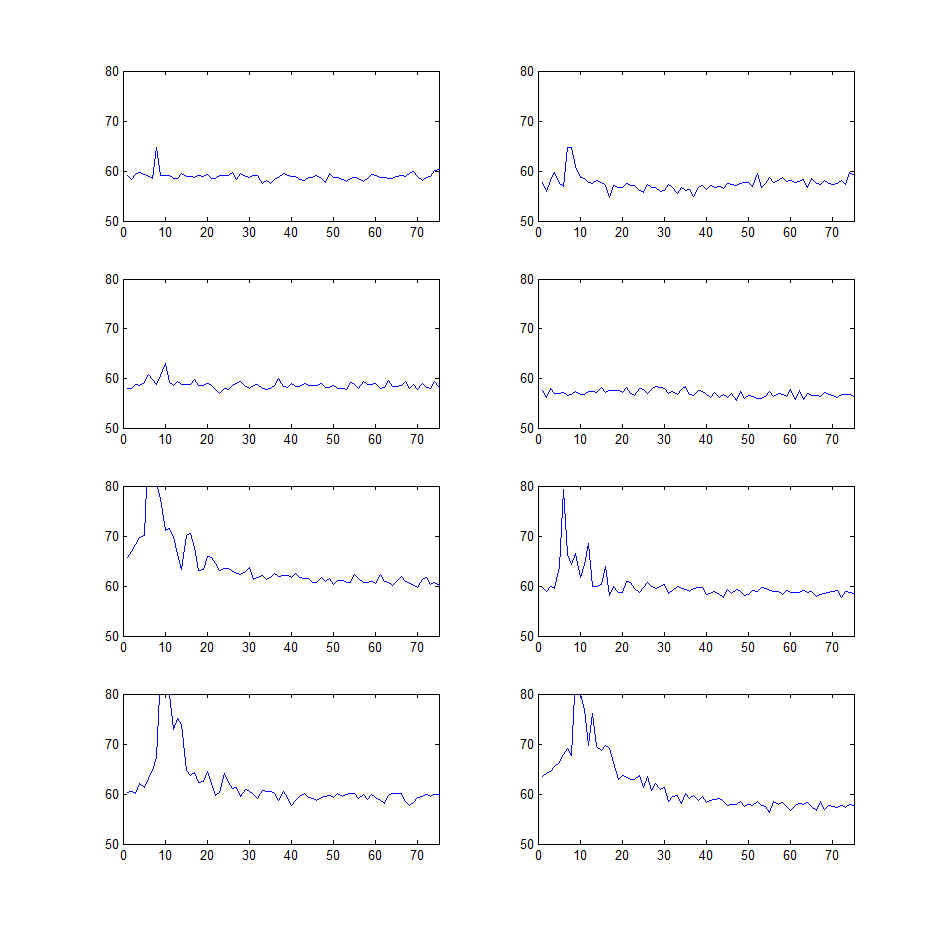
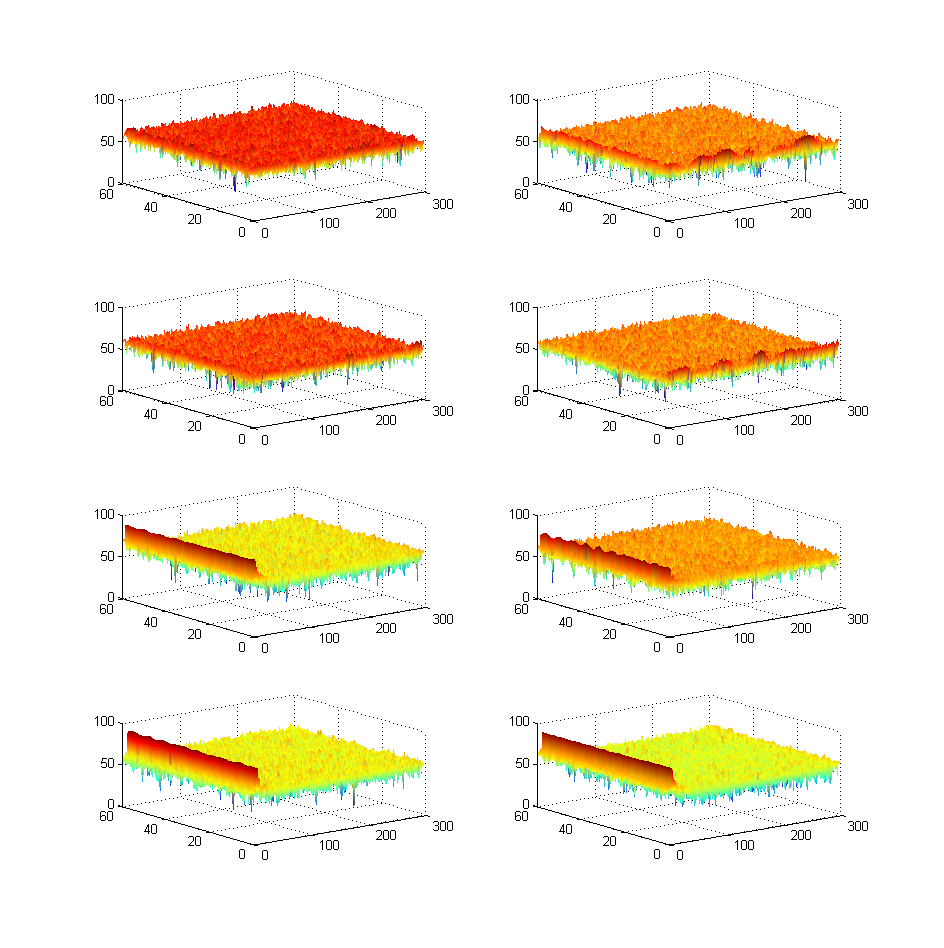


Figure 7: The first has no contact with the train and the second has LoS

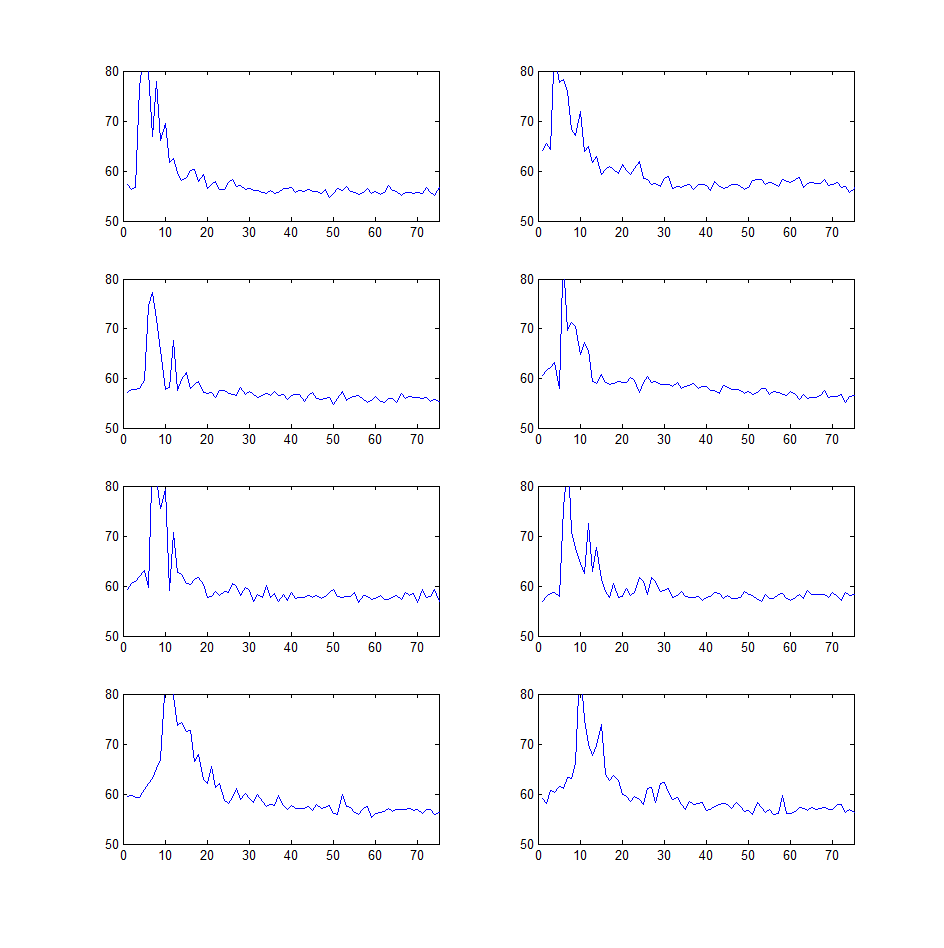
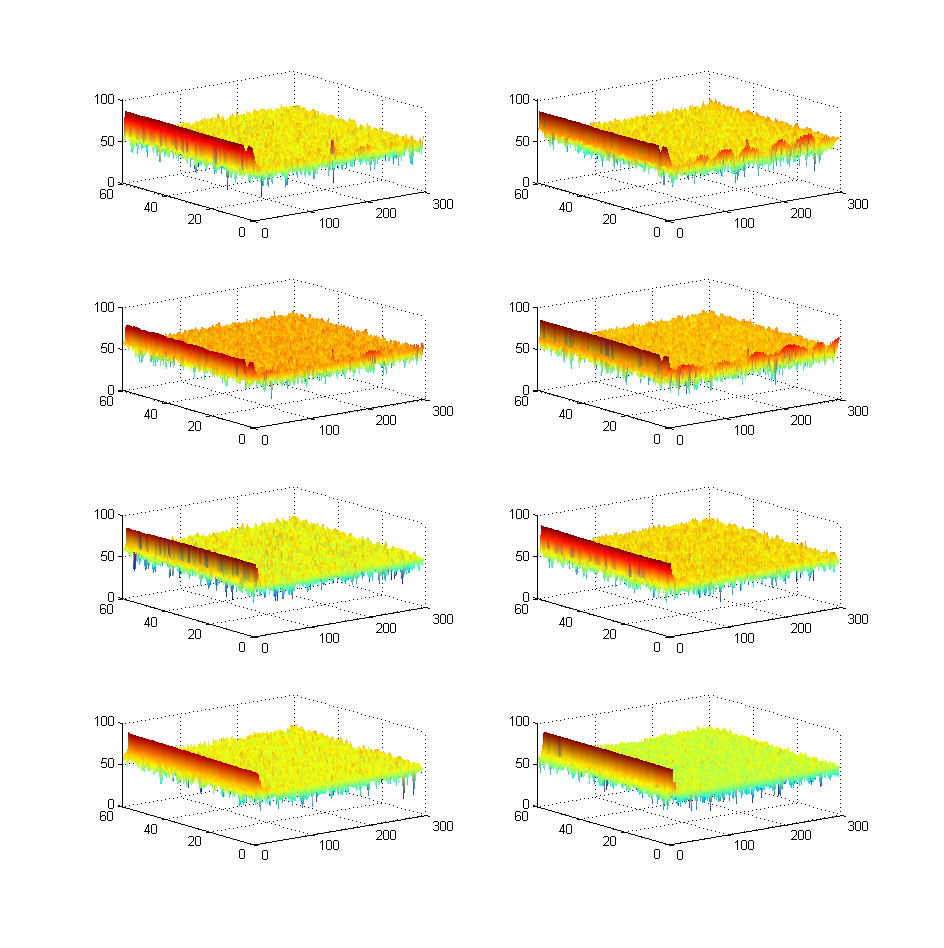


Figure 8: Both antennas have LoS (1st carrier)

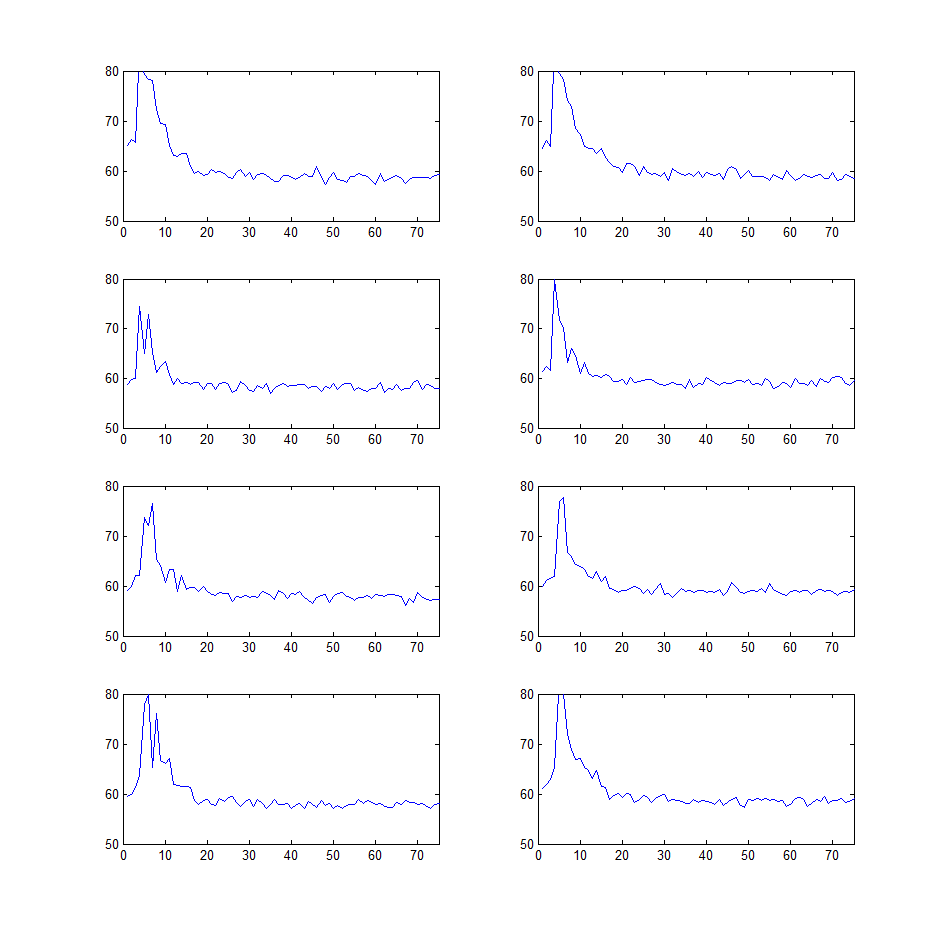
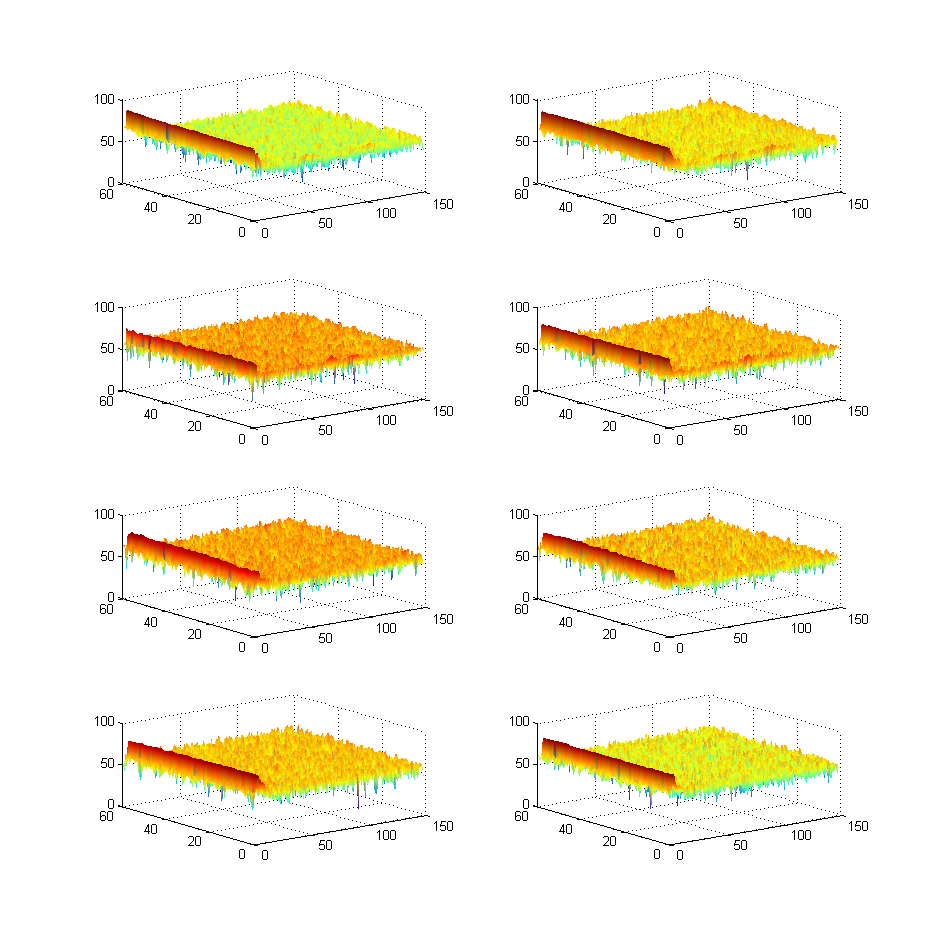


Figure 9: Both antennas have LoS (2st carrier)

## Doppler profile estimation

# References

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2. Paier, A., Karedal, J., Czink, N., Hofstetter, H., Dumard, C., Zemen, T., ... & Mecklenbrauker, C. F. (2007, October). Car-to-car radio channel measurements at 5 GHz: Pathloss, power-delay profile, and delay-Doppler spectrum. In *Wireless Communication Systems, 2007. ISWCS 2007. 4th International Symposium on* (pp. 224-228). IEEE.
3. Minn, Hlaing, Mao Zeng, and Vijay K. Bhargava. “On Timing Offset Estimation for OFDM Systems.” *Communications Letters, IEEE* 4, no. 7 (2000): 242–44.
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5. http://en.wikipedia.org/wiki/Lanczos\_resampling